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Cavity nucleation and growth during helium implantation and neutron irradiation of Fe and steel

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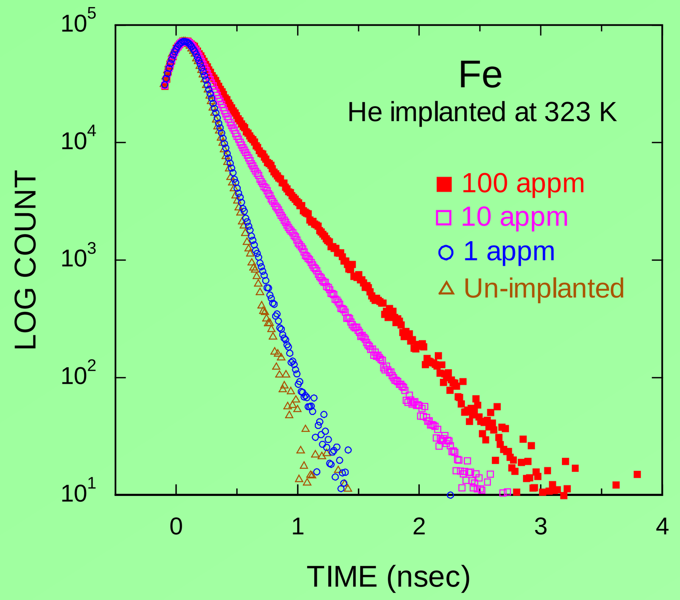


Introduction:

In order to investigate the role of He in cavity nucleation in neutron irradiated iron and steel, pure iron and Eurofer-97 steel have been He implanted and neutron irradiated in a systematic way at different temperatures, to different He and neutron doses and with different He implantation rates.

The defect microstructure, in particular the cavities, was characterized using Positron Annihilation Lifetime Spectroscopy (PALS) and Transmission Electron Microscopy (TEM).

Experimental Details:

Specimens used for the experiments were pure iron and Eurofer-97. They were He implanted uniformly at the Jülich Compact Cyclotron. Subsequently many of the specimens were neutron irradiated in the BR-2 reactor at Mol, Belgium.

The He implantation and neutron irradiation parameters were:

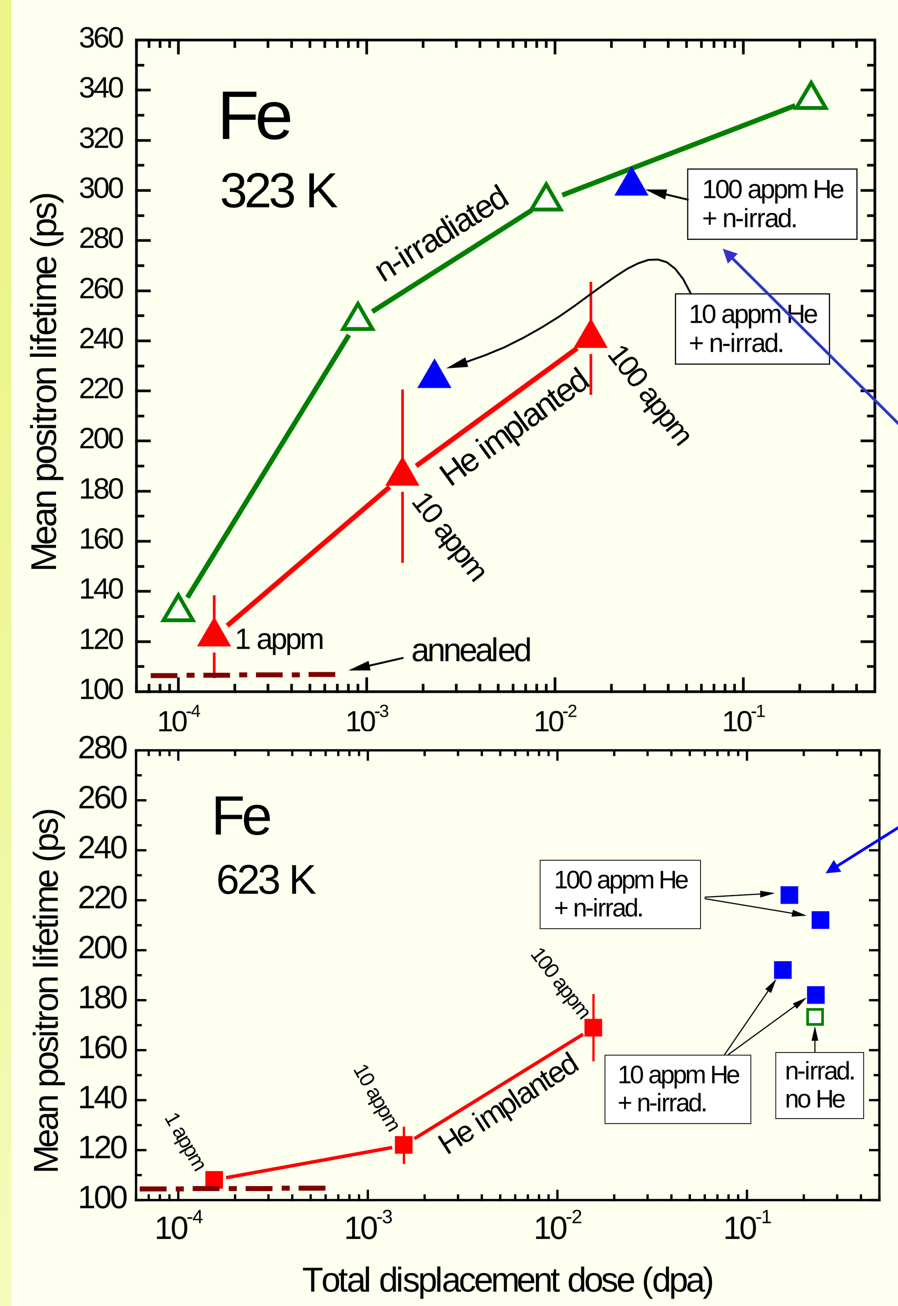
T_{impl} = T_{n-irr} (K)	He dose (appm)	He dose rate (appm/s)	Neutron dose (dpa)
~ 323 K	1, 10, 100	6 10^{-4}-1.2 10^{-2}	0.001 – 0.1
623 K	1, 10, 100	1.2 10^{-3}-1.2 10^{-2}	0.1 – 0.3

100 appm He gives rise to a displacement damage of 0.015dpa.

PALS measurements were carried out on specimens that were He implanted, neutron irradiated or neutron irradiated after He implantation. Results are presented here in the form of positron mean lifetimes.

A few of the specimens were also investigated by TEM.

IRON



Positron mean lifetimes for He implanted, for neutron irradiated and for He implanted plus neutron irradiated iron as functions of displacement dose.
$T_{impl.}$ = $T_{n\text{-}irr.}$ = 323 K or 623 K.

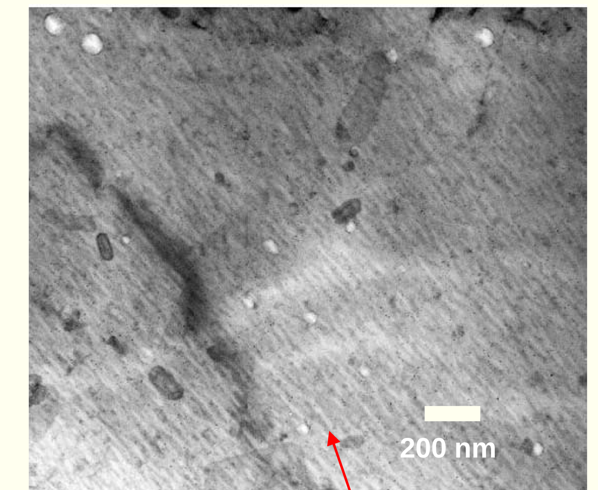
PALS

Both n-irradiation and He implantation lead to the formation of cavities of nanometer size both at 323K and at 623K as evidenced by the increase of the positron mean lifetime with displacement dose.

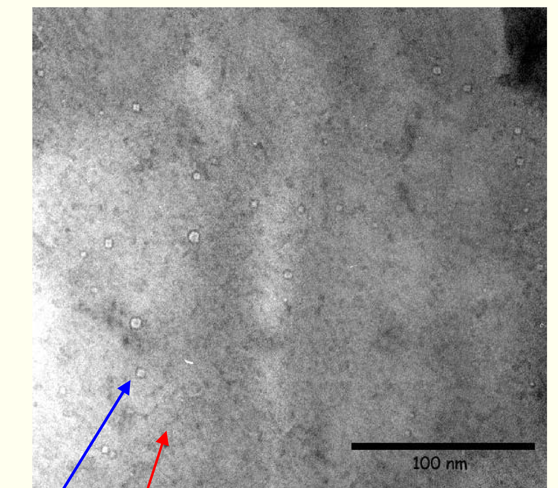
At 323K the presence of He does not seem to enhance cavity production by neutron irradiation.

At 623K a clear effect of He is observed. This agrees with TEM observations.

The 323K-data for He-implanted (as well as n-irradiated) specimens reflect the presence of a high density of sub-nm sized cavities, too small to be observed by TEM.



323K; 100 ppm He; n-irradiated 0.1 dpa. Void size ~ 52 nm; density ~ 2 10^{19} m^{-3} .

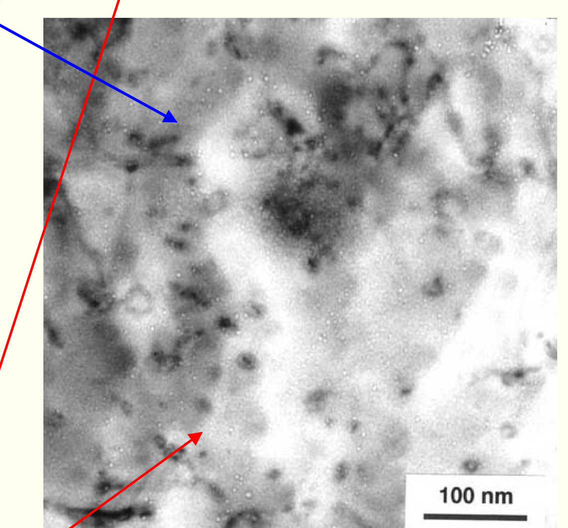


623K; n-irradiated 0.23 dpa. Void size ~ 4.0 nm; density ~ 1.5 10^{21} m^{-3}

TEM

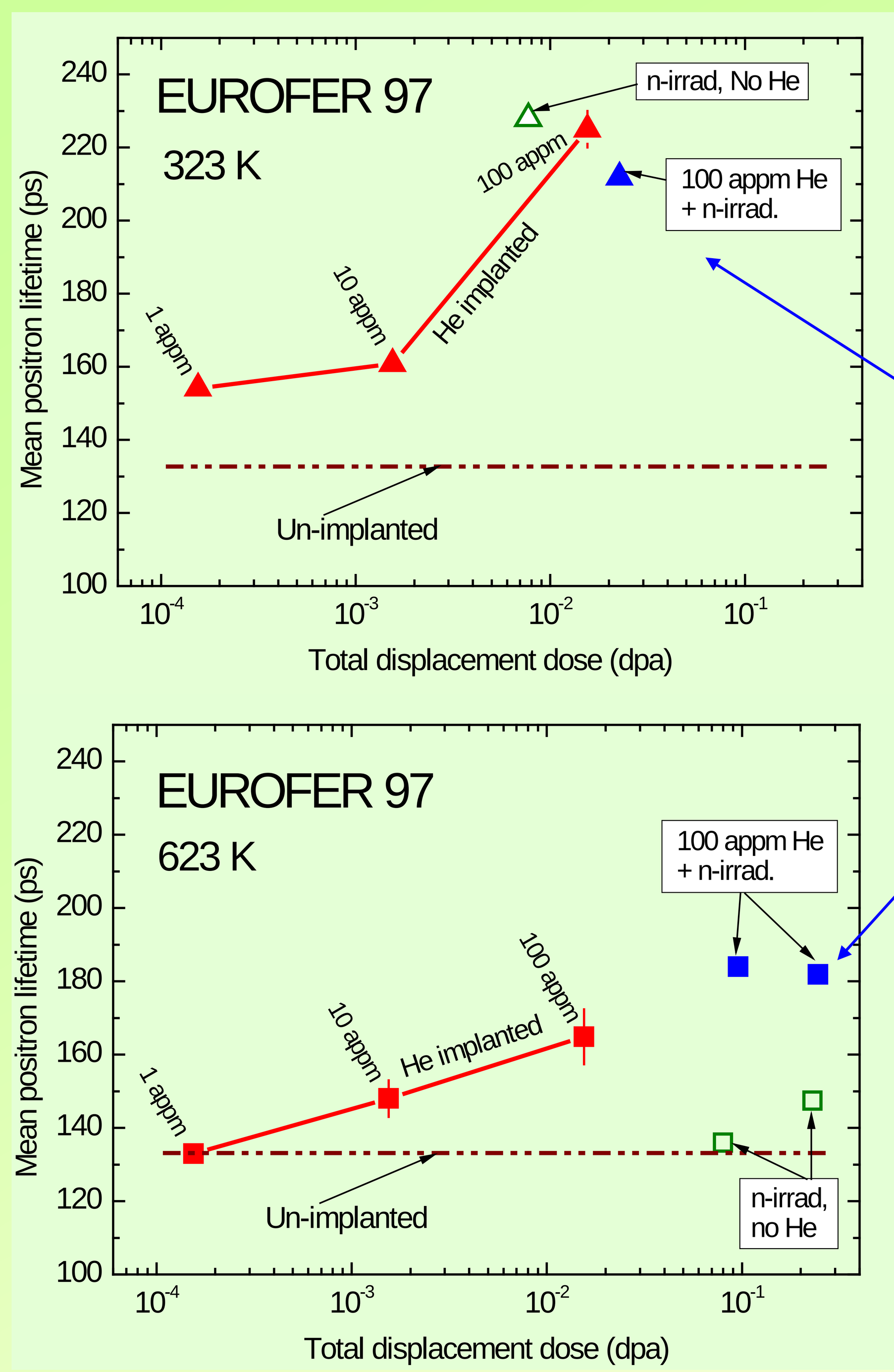
No voids are observed by TEM after neutron irradiation at 323K to the dose levels used in the present experiments. However, unexpectedly, large voids of low density were observed if He was implanted before irradiation with neutrons.

Neutron irradiation at 623K (i.e. above stage V) produces a fairly high density of voids. If 100 ppm of He is implanted before n-irradiation, the density of cavities increases by a factor of ~7.



623K; 100 ppm He; n-irradiated 0.23 dpa. Cavity size ~ 3.5 nm; density ~ 10^{22} m^{-3} .

EUROFER-97



Positron mean lifetimes for He implanted, for neutron irradiated and for He implanted plus neutron irradiated Eurofer-97 for different displacement doses.
$T_{impl.}$ = $T_{n\text{-}irr.}$ = 323K or 623K

PALS

Like for Fe both n-irradiation and He implantation lead to the agglomeration of vacancies into small cavities both at 323K and at 623K as evidenced by the increase of the positron mean lifetime with displacement dose. However, the effect is appreciably smaller than for iron.

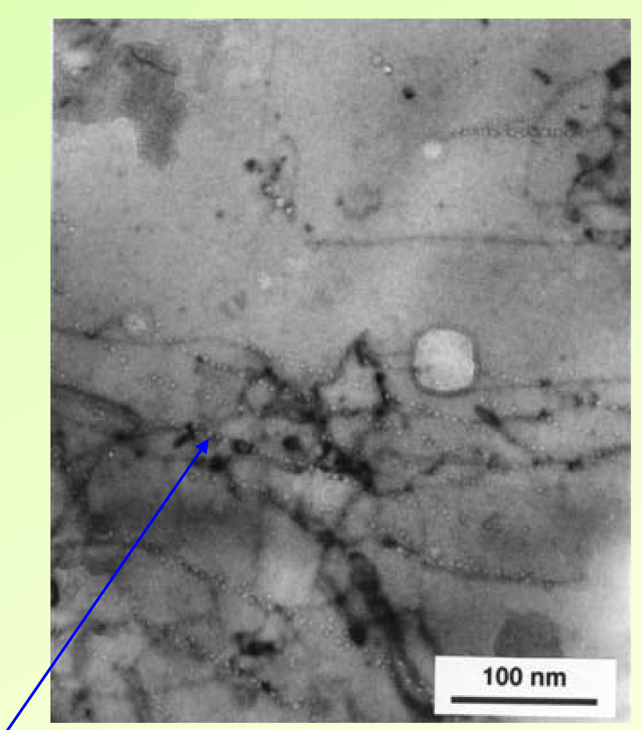
At 323K the presence of He does not enhance cavity production by neutron irradiation.

Probably - like for Fe – this is because He bubbles constitute only a minor fraction of the total cavity population.

At 623K, on the other hand, a clear effect of He is observed.

TEM

At 623K post-implantation neutron irradiation leads to a heterogeneous population of cavities.



623K; 100 ppm He; n-irradiated 0.23 dpa. Very inhomogeneous cavity distribution. Cavities seem to form only at dislocations and interfaces, except for a very low density of large voids.

Summary:

This poster gives a brief overview of a study of the microstructure, in particular the cavity population, in iron and Eurofer-97 after He implantation and neutron irradiation.

Both He implantation and neutron irradiation create populations of cavities.

At 323K pre-implantation of He only influences the effect of neutron irradiation to a small extent..

At 623K on the other hand, He strongly enhances the density of cavities after neutron irradiation.

Thanks to: *S.I. Golubov*,